Lateral Mixing
Progress Report

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LONG-TERM GOALS

Our long-term goal is to understand how energy is supplied to the ocean, and how it subsequently cascades to the turbulence and mixing important to the circulation, and the transport and distribution of tracers. This problem involves scales spanning sub-inertial motions to turbulence, and therefore requires integrative efforts with other sea-going investigators and numerical modelers. The Lateral Mixing Experiment project was an ideal opportunity to investigate the cascade from mesoscale processes to the submesoscale.

OBJECTIVES

To characterize lateral variability in the upper ocean as it responds to mesoscale forcing.

APPROACH

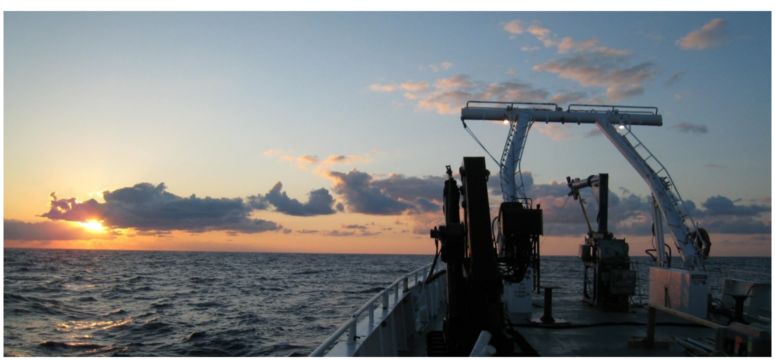

Figure 1: MVP system deployed from stern of* R/V Endeavor *in Sargasso Sea.

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My approach for understanding this problem has been to make lateral measurements of temperature and salinity structure, and to remove the effect of internal waves by mapping this structure onto isopycnals. This has been very successful in elucidating lateral structure in the North Pacific, and now we are applying the same techniques to the North Atlantic.

WORK COMPLETED

I worked hard with the numerical modelers on this project, in particular Jeroen Molemaker, on thinking about how the sampling should go on this project. In particular, there is a gap with respect to understanding where we will have large submesoscale activity based on external forcing. This work was only partly satisfactory, and in particular, it seems that there needs to be better ways of statistically characterizing when we will have enhanced lateral variability. Numerical models are a good way to start, because they have all the scales present, and confounding influences like internal waves are less prevalent.

SUMMER 2011

I also participated in the sea-going part of this project, taking my group on the *R/V Endeavor* in June 2011. Our role was to sample around the center of the dye patch on approximately 15 km scale (figure 3), using the Moving Vessel Profiler. We did this on two deployments "Site 1" and "Site 2".

WINTER 2012

I was chief scientist on the *R/V Atlantis* for the Feb/Mar 2012 expedition. My group had the Mving Vessel Profiler, and we worked with Kipp Shearman and his glider group, and Miles Sundermeyer and Jim Ledwell's dye group. Our primary role was to do larger scale surveys around the *R/V Knorr* while also tending the gliders, and deploying dye.

All aspects of this part of the experiment went very well. Despite very inclement weather, we only had approximately 12 h of down time, and collected over 70 crossings of the Gulf Stream, as well as completing a very large survey to document mixed layer vorticity south of the Gulf Stream.

RESULTS

SUMMER 2011

We are still assessing our results from June. Preliminary analyses indicate that we were very successful in characterizing the T-S characteristics around the dye patch (figure 4). Unfolding our butterflies indicates that we passed through the same water on multiple passes, and that changes in the horizontal structure of the water mas should be readily apparent from those passes (figure 5).

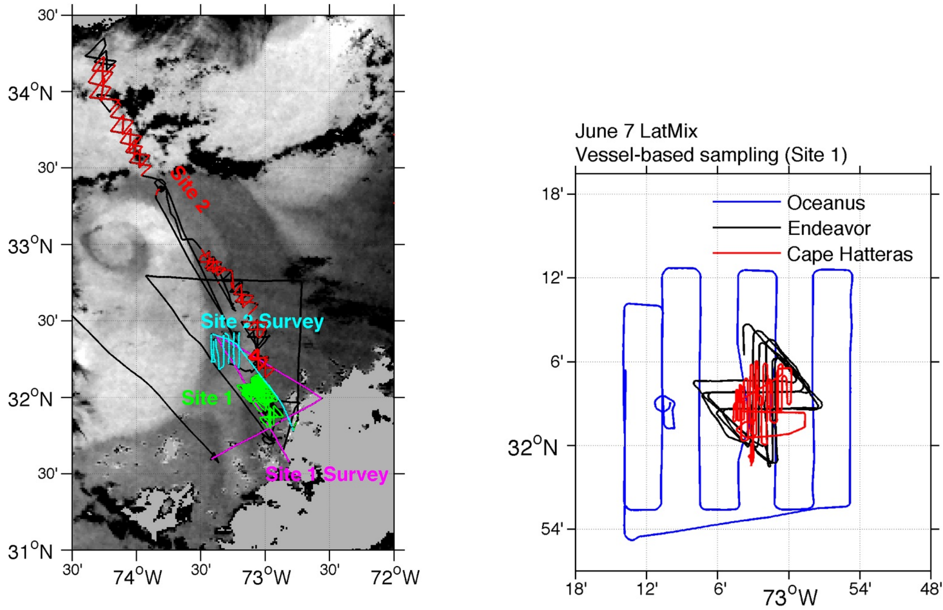

Figure 2: Left) Site sampling by the MVP. Site 1 Survey had 389 casts, Site 1 sampling consisted of 2597 casts; The Site 2 survey was 509 casts, and Site 2 had 964 casts. Right) Example day of sampling during survey 1. The* R/V Oceanus *provided large-scale context, while the* R/V Cape Hatteras *sampled dye at high resolution. UVic's MVP group on the* R/V Endeavor *provided the medium scale, centered on the dye.

Site 2 is was more energetic, at least translating very quickly in space (figure 3). We had a few technical glitches during this leg, as well as the need to corral floating assets, so the time series is not as continuous. However, we did collect a nice array of data (figure 6) across the front that we hope will be very useful in diagnosing submesoscale changes during the deployment.

WINTER 2012

The winter cruise yielded a rich data set that will provide a wealth of context for the close-spaced surveys on the *R/V Knorr*. These results have all been disseminated to my colleagues and progress is being made on their analysis.

A process we became very curious about was the separation of tendrils of warm salty water from the north wall figure 7. These tendrils formed at the crest of Gulf Stream meanders and spun fluid off as far sat 20 km, with tendrils extending on the order of 100 km. The appear to have positive vorticity, with the tendrils moving slower than both the Gulf Stream and the cooler water trapped between them and the Gulf Stream.

Most interestingly, these tendrils have a lateral structure that is coherent with depth, crossing isopycnals, though at a substantial slope to the front (figure 8). These tendrils are revealed very clearly

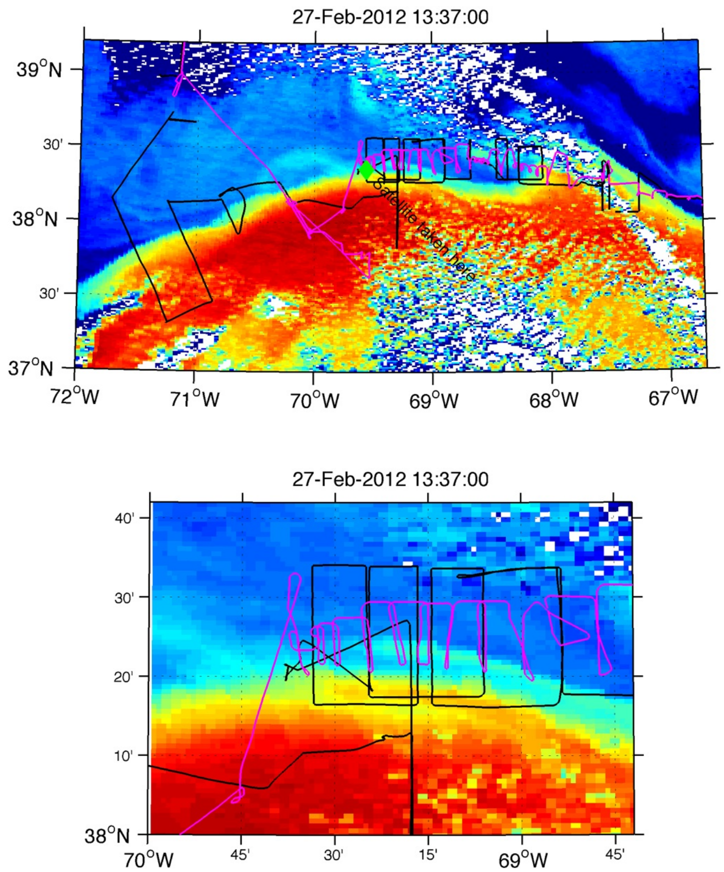

Figure 3: Example frontal sampling winter 2012. Magenta was the* R/V Knorr*, Black was the* R/V Atlantis*.

in the MVP sections we took, and are likely unobserved previously because previous surveys of the Gulf Stream were made at too coarse a resolution.

We are still trying to figure out these features, but they appear related to baroclinic instability set off at the tips of the meanders. Similar structures are seen in simplified models of the Gulf Stream, though their baroclinic dynamics have not been documented in my literature search. We will also work closely with Jim McWilliams and Jeroen Molemaker and their students on replicating this effect in their numerical models, and determining the overall importance of these features to the mixing of the Gulf Stream.

IMPACT/APPLICATIONS

We have collected one of the few repeat observations on the submesoscale of water that was tracked by dye and floats. Being able to follow a parcel of water in this manner was crucial, and we expect going to be very rich in understanding the phenomenology at these scales. Work is just starting on the data set in collaboration with our colleagues on the DRI.

We can see a number of papers resulting from the winter cruise, many of which will be lead by my

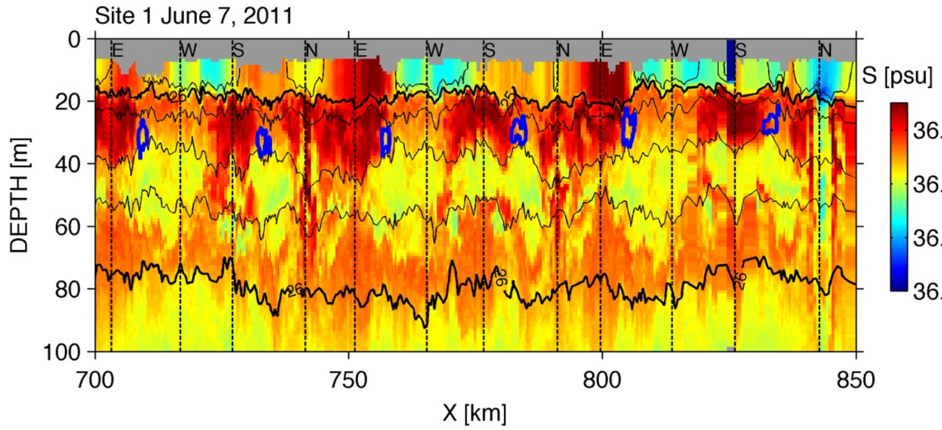

Figure 4: Three and a half example butterfly sections at Site 1. Blue contours are dye encounters. Turns are noted with vertical dashed lines and labeled by where they were in the butterfly.

co-PIs on the project. I will be taking the lead on understanding the tendrils observed on the North Wall, and documenting their importance, an analysis we think will be high-impact.

RELATED PROJECTS

This work is related to the efforts of the other DRI investigators. We will be working closely with Craig Lee, Eric Kunze, Kipp Shearman and Tom Sanford to understand how the various scales mesh together in our observations.

The winter efforts have already been shared with my co PIs (much of it while at sea!), and we are all working on an integrated analysis of the data. I will also be working with the modeling group at UCLA on matching the winter time data with the observations, with emphasis on understanding the observed baroclinic tendrils, both their importance, and their mechanics.

This work is also related to work from my Canadian NSERC Grant, where we have been trying to go to Line P to make similar observations in the North Pacific.

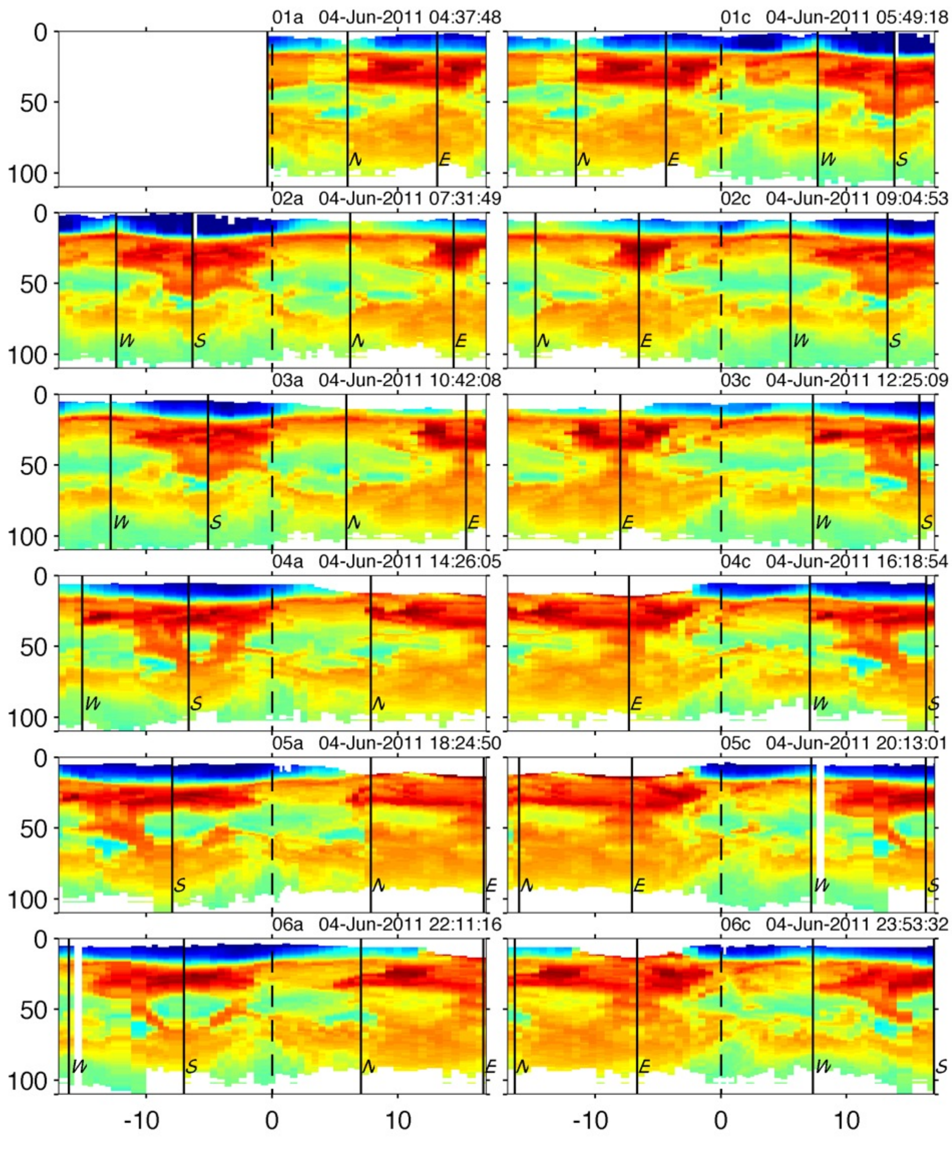

Figure 5: Butterfly patterns unfolded and put onto isopycnal vertical reference frame. These results indicate that we did a relatively good job of sampling similar water, and that changes over time were subtle at Site 1.

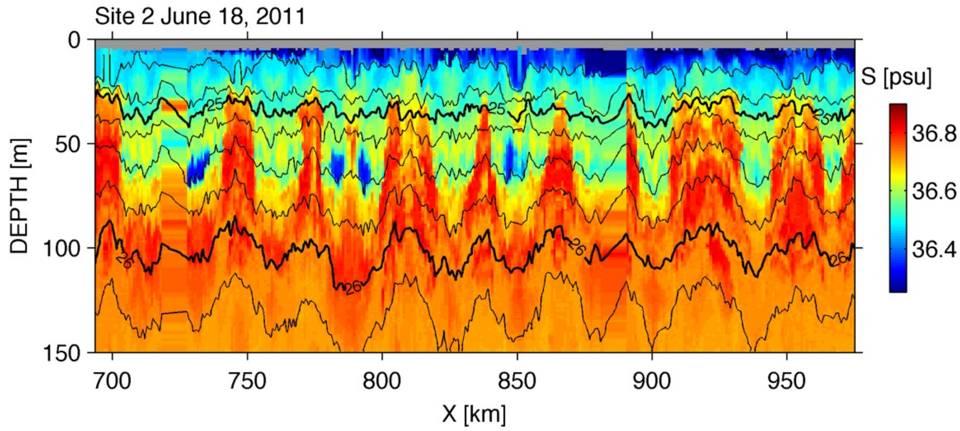

Figure 6: Site 2 example data. Note in this case the water did change significantly as we ran our butterflies.

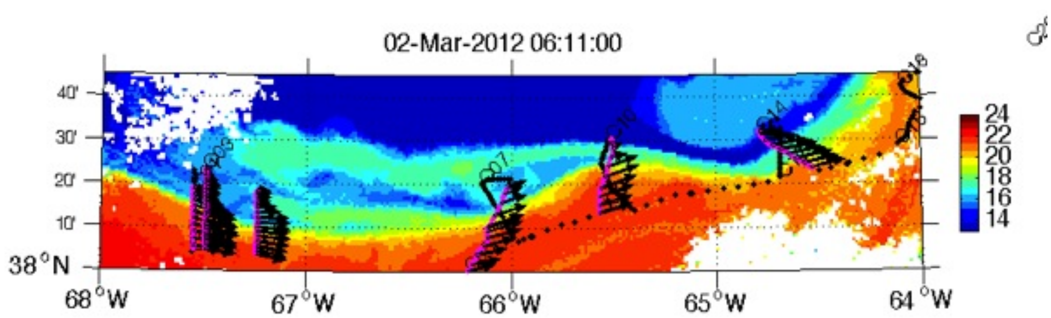

Figure 7: Sampling pattern in 2012 overlaid on top of satellite photograph. Currents are indicated with arrows.

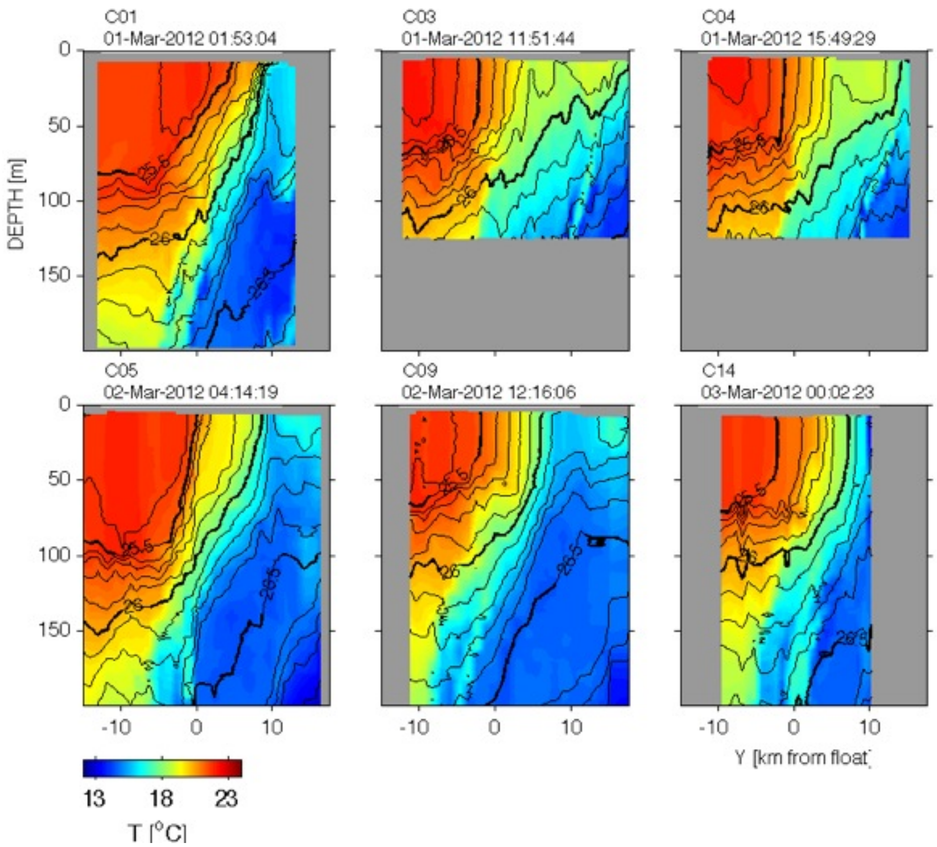

Figure 8: Salinity sections showing warm (salty) filaments reaching to 200 m being ripped off the north wall of the Gulf Stream.